Hydrogeology of surficial, unconsolidated quaternary aquifers, Maynard Creek catchment, Bridger Range, Montana
by John F Whittingham

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Earth Sciences
Montana State University

Abstract:
The groundwater regime within the Maynard Creek catchment is poorly defined. Aquifers may exist in fractured bedrock and surficial, unconsolidated Quaternary deposits. Ski area and residential development within the catchment has increased water demands. This investigation addresses the following questions: 1) Do the surficial, unconsolidated Quaternary deposits function as aquifers?; 2) Can surficial aquifer discharge be distinguished from bedrock aquifer discharge?; and 3) Can the surficial aquifers be characterized? The techniques used in this investigation include: 1) geologic mapping; 2) stream hydrograph and flow duration curve analyses; 3) groundwater discharge monitoring; 4) hydrogeochemical analyses; 5) material sampling; and 6) seismic refraction.

Geologic mapping was completed to delineate potential aquifers. Groundwater discharge features, including 62 springs, are strongly clustered within surficial deposits. Most springs and seeps, and all perennial streamflow exist at lower elevations where surficial deposits are thickest. Stream hydrograph analyses indicate that discharge is sustained by direct surface water runoff and that groundwater discharge is limited.

Springs within surficial deposits display rapidly increased yields after intense precipitation and snowmelt runoff. Three perennial springs exist and each discharges from surficial deposits. These springs yield between 3 lps (0.1 cfs) and 28 lps (1.0 cfs).

Spring water temperatures decrease with increased elevation by 1.0° (1.8°F) per 100 m (328 ft). Groundwater discharges from surficial deposits have low winter temperatures (2 to 4°C, 36 to 39°F) that steadily increase through the summer. The average temperature variability of the most persistent surficial springs is 1.9°C (3.4°F). Water temperatures of bedrock springs are higher (5.0°C, 41°F), with an average variability of 0.2°C (0.4°F). Water temperatures of discharge from surficial deposits are rapidly depressed 0.1 to 1.0°C (0.2 to 1.8°F) by meteorological and snowmelt runoff events. The most productive perennial spring's annual water temperature cycle mimics the annual mean daily air temperature cycle with a lag time of 60 days.

Specific electrical conductance of all 62 spring waters was 0.16 to 0.50 (mS). This indicates low ionic concentrations of total dissolved solids and short residence times for stored groundwater. Springs flowing from surficial deposits discharge Ca (calcium) and HCO_3 (bicarbonate) enriched waters. Well waters derived from bedrock are Na (sodium) and HCO_3 (bicarbonate) enriched.

Material sampling and seismic refraction indicate that rock glacier till, undifferentiated till, outwash, and buried channels are the primary components of surficial aquifers. Porosity, storativity, and hydraulic conductivity were approximated for Quaternary materials. Rock glacier till, outwash, and buried channels yield rapid and intermittent groundwater discharge. Undifferentiated tills sustain perennial stream baseflows. The surficial Quaternary aquifers have development potential, but excessive winter withdrawals will reduce perennial stream baseflows.

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APPROVAL

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John Frederic Whittingham

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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VITA

John Frederic Whittingham was born to David and Helen Whittingham in Williamsburg, Virginia on November 6, 1959. He attended elementary through high school grades in Colorado Springs, Colorado, and graduated from Thomas B. Doherty High School in 1977. Mr. Whittingham attended the University of Colorado in Boulder from 1977 to 1979 and participated in general studies and Earth Sciences. Between 1979 and 1981, Mr. Whittingham completed Emergency Medical Technician certification at Pikes Peak Community College in Colorado Springs, and pursued Ski Area Management and avalanche studies at Colorado Mountain College, in Leadville and Breckenridge, Colorado. He was a member of the El Paso County, Colorado, Search and Rescue between 1979 and 1981. In 1981, Mr. Whittingham enrolled at the University of Montana in Missoula. In 1986, he completed a B.A. in Geology with a professional emphasis in Hydrogeology, and a B.A. in Geography with a corollary field in Watershed Management. Mr. Whittingham worked as a teacher, builder, and geologist from 1986 to 1990. In 1990, Mr. Whittingham initiated graduate studies in Earth Sciences at Montana State University, in Bozeman. He completed a M.S. in Earth Sciences in 1996. He also completed the Center for High Elevation Studies program requirements at Montana State University. In 1992, Mr. Whittingham worked as a hydrologist technician for the United States National Forest Service, Beaverhead National Forest, in Dillon, Montana. In 1993, Mr. Whittingham began permanent employment as a hydrologist with the Bureau of Land Management, Dillon Resource Area, in Dillon, Montana. Mr. Whittingham is currently employed (1996) by the Bureau of Land Management in Dillon, where he administers the Soil, Water, and Air, and Hazardous Materials Programs.

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INTRODUCTION

Groundwater storage and availability in steep mountainous terrain is highly variable and often limited by geologic constraints. In southwestern Montana, groundwater development in Upper Cretaceous rocks often produces low yields and poor water quality, while several Mississippian through Lower Cretaceous formations provide excellent groundwater quantity and quality (Miller, 1974, Moore, 1984, Ferreira and others, 1986). Overlying Quaternary deposits also may function as aquifers, but often they are clayey and do not transmit useful amounts of water, or lack sufficient storage volume to fulfill even modest human needs. In most cases, inadequate data exists for the hydrogeologic regime of mountain aquifer systems to be fully understood.

In the Maynard Creek catchment, on the eastern flank of the Bridger Range (Figure 1), steeply dipping Paleozoic through Upper Cretaceous bedrock is overlain by an undetermined thickness of unconsolidated Quaternary materials. Summer observations reveal an abundance of springs and seeps, and vigorous stream flow. During winter, few springs flow and stream discharge is minimal. The nature of groundwater occurrence in the catchment is unknown.

Resort development plans and increasing recreational activities in and around the Maynard Creek catchment have resulted in demands for additional consumptive and nonconsumptive water uses. Surface water availability from Maynard Creek is severely limited. Surface water is overappropriated and typical summer discharge is less than existing claimed water rights (Morrison-Maierle, Inc., 1978). Groundwater may be a viable resource to supplement the current and future water demands.

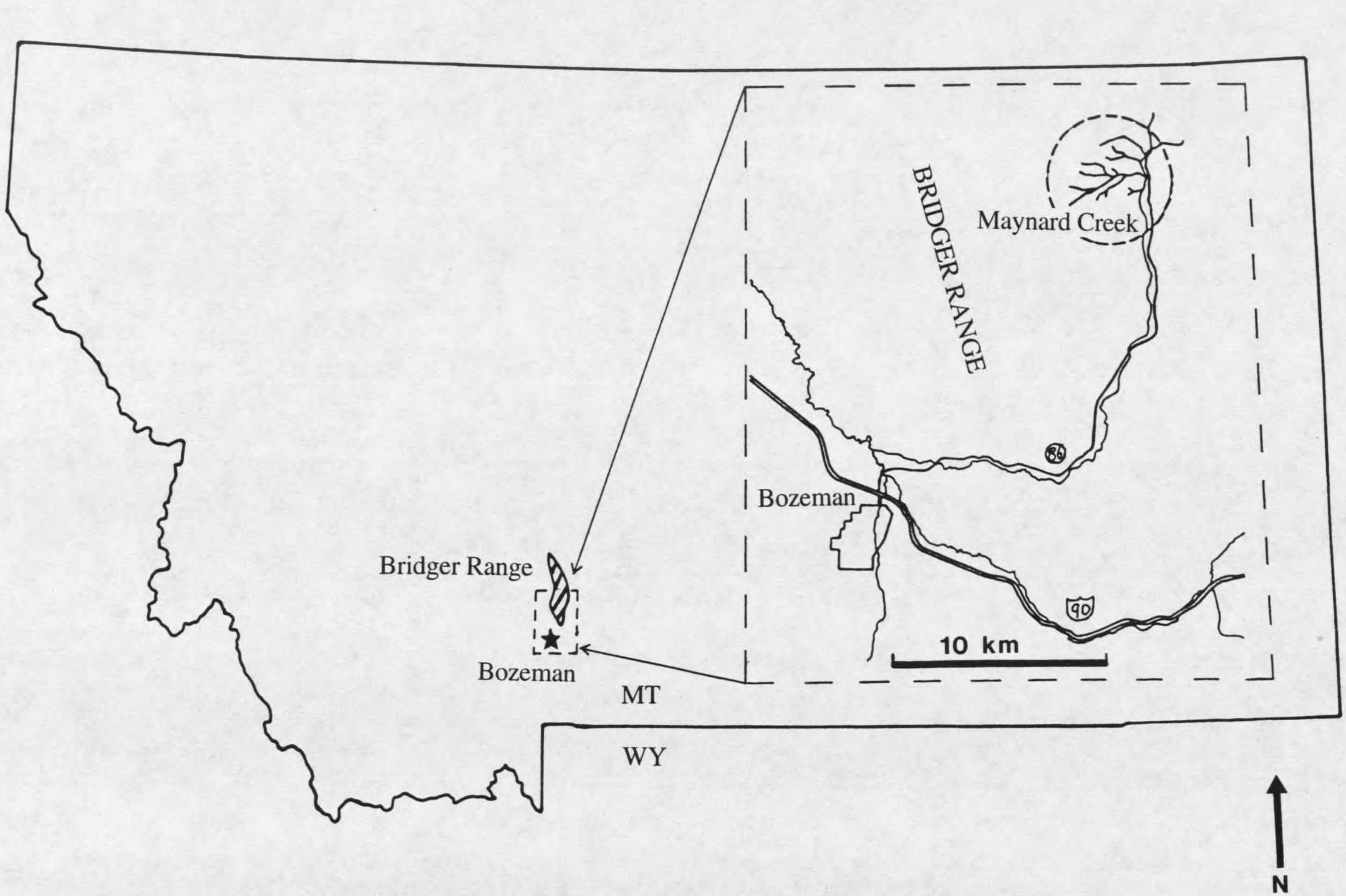

Figure 1. Location of the Bridger Range and the Maynard Creek catchment.

The problem of groundwater development in the catchment is that potential bedrock and surficial Quaternary aquifers have not been identified, and the capacity for water production from these materials is unknown. The purpose of this investigation is to determine the significance of surficial Quaternary aquifers. The objectives are to identify surficial, unconsolidated Quaternary aquifers; to distinguish surficial, unconsolidated Quaternary aquifer waters from bedrock aquifer waters; and to characterize the components of the surficial, unconsolidated Quaternary aquifer system in the Maynard Creek catchment.

Geographic Setting

The Maynard Creek catchment is on the eastern flank of the central Bridger Range, approximately 26 km (16 mi) northeast of Bozeman, Montana (Figure 2). Maynard Creek flows into Bridger Creek, which is a main tributary of the East Gallatin River. The catchment is east facing and has 883 m (2897 ft) of local relief, rising from 1774 m (5820 ft) at Bridger Creek to 2657 m (8717 ft) on the crest of the Bridger Range. A total of 5.6 km^2 (2.2 mi^2) are contained within the catchment boundaries (Figure 2).

Structural Geology

The structural geology of the Bridger Range has been described by McMannis (1955) and Lageson (1989). The Range is a small north-trending uplift which is approximately 40 km (25 mi) in length. It is located about 80 km (50 mi) east of the Boulder batholith, and constitutes a part of the Northern Rocky Mountain Front. The Bridger Range is unique in that it overlaps the boundaries of four major tectonic provinces. These tectonic provinces are: 1) the Middle Proterozoic Belt Basin; 2) the Sevier fold and thrust belt; 3) the Laramide foreland province of basement involved deformation; and 4) the Basin and Range province